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Original communication

Carbon monoxide poisoning as a cause of death and differential diagnosis in the forensic practice: A retrospective study, 2000–2010

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ABSTRACT

This study presents the epidemiology and the *postmortem* forensic aspects in cases with a carboxihemoglobin (COHb) analysis, from autopsies performed at the Forensic Pathology Department of the Centre Branch of the National Institute of Legal Medicine and Forensic Sciences of Portugal. Between January 2000 and December 2010, 69 COHb analyses were requested in our institution. In approximately 70% of the situations, circumstantial information included a Carbon Monoxide (CO) source at the death scene. More than half of the cases presented thermal lesions, cherry-red lividity, and cherry-red blood and viscera coloration were found in, approximately, 30% of the cases. Fourteen cases were recorded as CO poisonings. The highest number of poisonings occurred in 2000, with most of the cases in winter (53.8%), in 51–60 years-old male individuals. 69.2% of the poisonings were accidental and the remainder were suicides, being fires the most frequent sources of CO (38.5%). Cherry-red lividity was present in 61.5% of the cases, and all of them presented cherry-red blood and viscera coloration. Older individuals and those with thermal lesions presented lower COHb levels, and politrauma was the most frequent cause of death among the negative cases. It is possible to conclude that the forensic aspects of CO poisonings interact in a complex way, and differential diagnosis is not straightforward. This study also emphasizes the role played by public prevention campaigns and improvement of heating appliances in reducing the number of accidental CO poisonings, and the importance of preventing urban and forest fires, the major source of CO among us.

1. Introduction

Carbon monoxide (CO) is a product resultant of the incomplete organic materials combustion. Natural sources of CO include forest fires and volcanic eruptions, even though it is mainly produced by human activity.[1] Automobile exhaust fumes, charcoal briquettes in confined spaces, and defective or improperly ventilated gas heating appliances are common sources of CO. Although nontoxic natural gas is now the primary source of domestic energy, its combustion with an insufficient supply of oxygen generates CO, with its own deleterious effects.[2] CO also results from heme catabolism, and has recently been recognized as a neurotransmitter.[3] Endogenous production and environmental exposure to CO account for carboxihemoglobin (COHb) baseline levels of less than 1–3% in nonsmokers, and up to 10% in smokers.[1,4] CO is odorless, colorless and tasteless, not easily detected by an exposed person, and since it has approximately the same air density, it can easily spread through confined spaces.[2] The general toxicity mechanism of CO depends on its exceptional affinity for hemoglobin, which is 200 times higher than that of oxygen, resulting in tissue hypoxia. Today it is recognized that CO may have a direct cellular toxicity.[1,4] Depending on the concentration of the gas in the air, the length of exposure and health conditions, CO effects can range from mild cardiovascular and neurobehavioral symptoms at COHb levels of less than 15–20%, to unconsciousness and death. Children, patients with

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coronary and lung disease and the elderly, can be more susceptible to a CO intoxication.[4–6]

In forensic practice, CO-related deaths can mainly result from accidents or suicides, being homicides very rare. Risser and Schneider (1995) reported that, in 417 CO-related deaths, over a ten year study in Vienna, the majority of cases were accidents, higher in winter months.[6] These findings are similar to those of Homer et al. (2005) in Cleveland, USA and Ait El Cadi et al. (2009) in Morocco.[7,8] Scene investigation often provides circumstantial indications of CO poisoning, and autopsy usually follows. Characteristic pathological findings include: cherry-red or bright pink livor, and bright cherry-red coloration of blood, musculature and viscera, consistent with levels of COHb higher than 30%.[9,10] They are important forensic clues to determine the cause of death, which is established after determining COHb levels higher than 50–60%, in *postmortem* blood samples. However, it is not easy to establish the role of CO as the cause of death, and the interpretation of lower or negative COHb levels in victims with concomitant morbidity can be difficult, namely when excluding natural death, since delayed CO-related death cases with suggestive circumstances may be present with negligible COHb in blood.[11] On the other hand, cherry-red livor can be absent[12] or result from body refrigeration and/or cyanide poisoning.[13] Increasing public awareness of the dangers of CO poisoning, improved the safety of heating and cooking appliances, and gas emission controls in transports may have been responsible for the decline in the number of unintentional CO-related deaths. Nonetheless, CO poisoning remains involved in over one half of all fatal poisonings worldwide, yearly.[4,5]

The purpose of this study was to investigate the epidemiology and forensic aspects related to CO poisoning, in cases with *postmortem* COHb analysis, from autopsies performed at the Forensic Pathology Department of the Centre Branch of the National Institute of Legal Medicine and Forensic Sciences of Portugal (INMLCF), between 2000 and 2010.

2. Material studied

Autopsy reports of all deaths performed at the Forensic Pathology Department of the Centre Branch of the National Institute of Legal Medicine and Forensic Sciences of Portugal (INMLCF), between January 2000 and December 2010, were reviewed. Data material consisted of 69 autopsy reports referenced to have a *postmortem* carboxihemoglobin (COHb) analysis request. COHb analyses were performed in *postmortem* blood samples, at the Forensic Toxicology Department of the Centre Branch of the INMLCF by a molecular absorption spectroscopy methodology.[14] Assessment of the examination protocols was conducted by means of a tabular database according to the following criteria: year, month, season of the year (January, February and March were considered winter months; April, May and June, spring months; July, August and September, summer months and October, November and December, autumn months), age, gender, occupation, underlying disease, medico-legal etiology, source of CO, cause of death, autopsy findings (lividity, thermal injuries, coloration of blood and viscera), and toxicological analysis results. These variables were studied, and relevant data was submitted to numerical analysis, using SPSS (Statistical Package for Social Sciences).

3. Results

3.1. COHb analysis requests

3.1.1. Year, month and season distribution

Between January 2000 and December 2010, 69 *postmortem* COHb toxicological analysis were requested and performed at the Centre Branch of the INMLCF. As presented in Fig. 1, the number of COHb analysis requests was higher in 2005, with 15 cases (21.7% of all requests). The years 2002 and 2006 presented the lowest number of requests, 2 (2.9%). COHb analysis requests were more frequent in March (13 cases, 18.8%) and winter (24 individuals, 34.8%) (Fig. 1).

3.1.2. Gender, age and occupation

A COHb analysis was requested in 44 male individuals (63.8%) and 25 female individuals (36.3%). The >70 years-old age group presented the highest number of COHb analysis requests (22 cases, 31.9%), and the age groups 11–20 years-old and <10 years-old were the groups with the lowest requests number (1 request – 1.4% and 2 requests – 2.9%, respectively) (Fig. 2). In 75.4% of the requests (52 cases), the information about the occupation of the deceased wasn't, *per se*, justification of a CO poisoning suspicion, whether because it was unknown (50.7% of all requests) or because the occupation wasn't associated to an increased risk of CO poisoning (24.6%). In 4 (5.8%) cases, the individual was a fireman, and in 13 (18.8%), a pensioner (Fig. 3). Among the cases not associated to an identifiable source of CO but with COHb analysis request, 4 (19%) individuals were pensioners, and in 17 (81%), the occupation was unknown or not associated to an increased risk of CO poisoning.

3.1.3. Etiology and source of CO

The medico-legal etiology indicated *natural death* in 11 requests (15.9% of all cases). Fifty individuals (72.5%) presented a

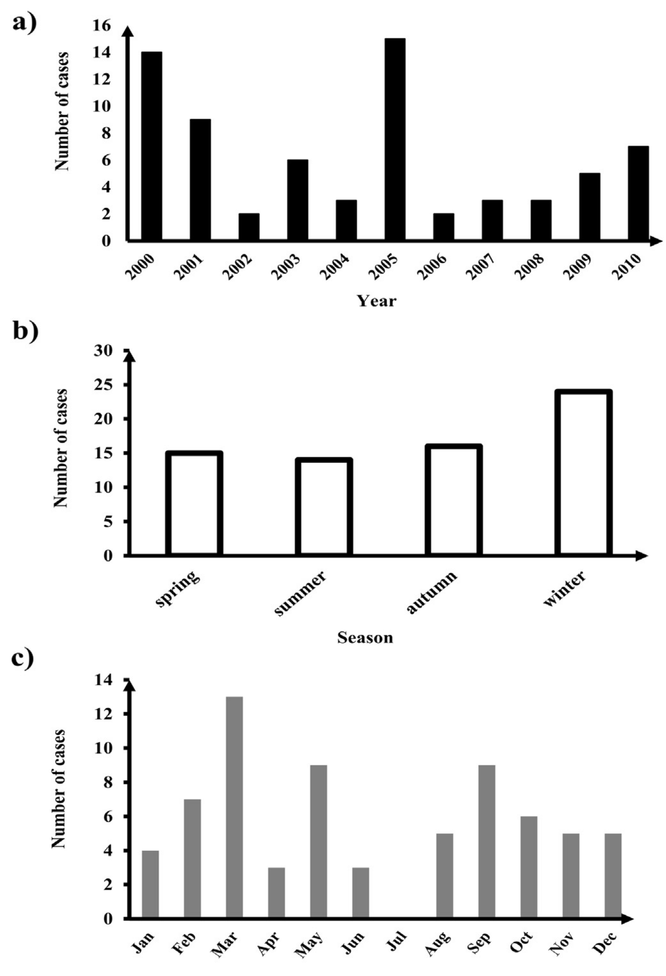

Fig. 1. COHb analysis requests distribution by year [a)], season [b)] and month [c)].

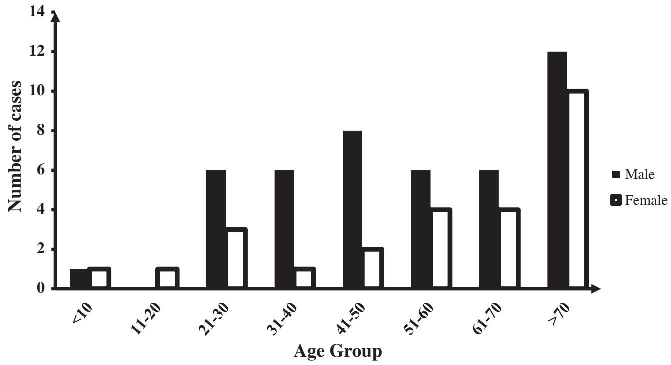

Fig. 2. Distribution of the cases with a COHb analysis request according to gender and age group.

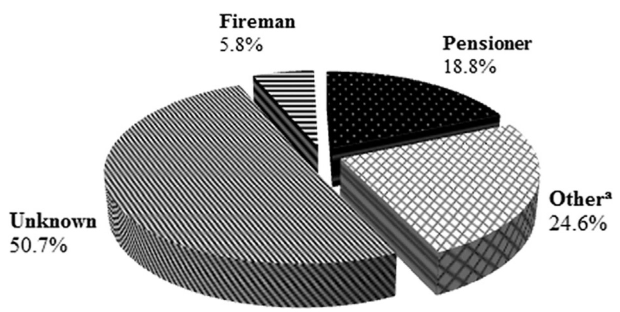

Fig. 3. Distribution of the cases with a COHb analysis request by occupation. [a]Includes all occupations without an increased risk of CO poisoning and that wouldn't, *per se*, justify an analysis request.

circumstantial information that suggested an unintentional (accidental) death, and 6 cases (8.7%) were suicides. Only 2 cases (2.9%) were related to homicides. There was a perfectly identified CO source at the death scene of 48 (69.6%) individuals. Thirty six individuals were fire victims (75% of the cases with an identified CO source and 52.2% of all cases with a COHb analysis request). Among suicides, 5 individuals (83.3% of all suicides) presented an identifiable source of CO. One of the two homicides with a COHb analysis request was a fire victim. The other case had no source of CO at the death scene, but presented thermal lesions.

3.1.4. Autopsy findings

Thermal lesions were described in 56.5% (39 cases) of the cases with a *postmortem* COHb analysis request. Cherry-red lividity was present in 21 individuals (30.4%). In 29% (20 cases), lividity was *bluish* and in 40.6% (28 individuals), lividity wasn't characterized because of skin pigmentation or large extent of thermal lesions. Among requests without an identifiable CO source, *bluish* livor was more frequent (61.9%, corresponding to 13 cases), but in 6 (28.6%) cases, lividity was cherry-red. Cherry-red coloration of the blood and viscera was found in 21 cases (30.4% of requests) (Table 1). In 7 cases (10.1% of requests), no poisoning associated to occupation, source of CO, or suggestive autopsy findings were described.

3.2. Positive analyses

3.2.1. COHb levels according to gender and age

COHb analysis was positive in 24 individuals (34.8% of all requests). In these cases, the lower COHb levels were achieved in the older people (Pearson Correlation Coefficient). Mean % COHb in positive cases was similar both in males and females (49 ± 27 vs. 51 ± 16 (SD) % COHb; Student's t-Test for Independent Samples, $p = 0.952$).

3.2.2. COHb levels according to autopsy findings

Cherry-red lividity was present in 9 positive cases (37.5%). In 2 cases (8.3%), lividity was *bluish* and in 13 cases (54.2%), lividity wasn't characterized. The type of lividity was not dependent on the COHb percentage (Mann–Whitney U Test for Independent Samples, $p = 0.906$). Fifteen cases (62.5% of all positive requests) presented cherry-red coloration of blood and viscera. Cases with cherry-red coloration of blood and viscera, had significantly higher COHb levels than the positive cases in which this finding was absent (58 ± 23 (SD) vs. 32 ± 17 (SD) % COHb; Mann–Whitney U Test for Independent Samples, $p = 0.012$). The lower COHb level, in a positive case that presented cherry-red lividity, was 3% COHb, which is similar to the lower COHb level achieved in a positive case that presented cherry-red blood and viscera coloration. The higher COHb concentration achieved in a positive case with *bluish* lividity was 82%, and it was 61% in a positive case without cherry-red blood and viscera coloration. 15 individuals (65.5%) also presented thermal lesions. In this group, mean % COHb was significantly lower than that of the group of individuals, without thermal lesions (41 ± 24 vs. 64 ± 18 (SD) % COHb, Mann–Whitney test, $p = 0.025$).

3.2.3. COHb levels according to cause of death

Among the positive cases, 11 cases had no CO poisoning as the cause of death (45.8% of the positive cases). In this group, 9 individuals (81.8%) died due to carbonization and 2 individuals (8.3%) as burns consequence. Mean COHb level in individuals with a positive analysis whose cause of death was not CO poisoning was of 32 ± 19 (SD) % COHb. Cherry-red lividity was found in only one individual (9.1%). One individual presented *bluish* lividity and, in the majority of the cases (9 individuals, 81.8%), lividity couldn't be characterized because of the extension of thermal lesions. Cherry-red blood and viscera coloration was found in 3 individuals (27% of the cases).

3.2.4. CO poisonings

3.2.4.1. Year, month and season distribution. CO poisoning was the cause of death in 14 cases with a *postmortem* COHb analysis (20.3%

Table 1
Characterization of the cases with COHb analysis request according to the source of CO found at the death scene and corresponding autopsy findings.

Source of CO	Analysis requests	Autopsy findings				
		Lividity			Thermal lesions *n* (%)	Cherry-red viscera *n* (%)
		Cherry-red, *n* (%)	*Bluish*, *n* (%)	Not characterized[b], *n* (%)		
Identified[a]	48	15 (31.3)	7 (14.6)	26 (54.2)	35 (72.9)	20 (41.7)
Not present	21	6 (28.6)	13 (61.9)	2 (9.5)	4 (19)	1 (4.8)
Total	**69**	**21 (30.4)**	**20 (29)**	**28 (40.6)**	**39 (56.5)**	**21 (30.4)**

[a] Includes fire, charcoal briquettes, burnt wood can, fire pan, defective gas appliance and fireplace.
[b] Refers to the cases in which the lividity was not characteristic, because of skin pigmentation or large extent of thermal lesions.

of all requests). This group included 13 cases (92.9% of all CO poisonings) with a positive analysis and 1 case (7.1%) in which the *postmortem* COHb analysis was negative. The highest number of fatal CO poisonings with positive COHb analysis occurred in 2000 (5 cases, 38.8% of all positive CO poisonings) and in February, March and May (3 cases, 23% each); the remainder occurred, equally, in January, February, April, November and December (1 case, 7.7% each). Winter was the season with the highest number of cases (7 cases, corresponding to 53.8% of all positive poisonings). Four cases (30.8%) occurred during spring, and two (15.8%) during autumn. No cases occurred during summer.

3.2.4.2. Gender, age and occupation. Male individuals account for the great majority of CO poisonings with a positive analysis, with 9 individuals (69.2%) (Table 2). Mean age in the group of positive CO poisonings was 42 ± 26 (SD) years. Distribution of positive fatal CO poisonings by age groups is presented in Fig. 4. In 61.5% (8 individuals) of positive CO poisonings, the victim's occupation was unknown. In 2 cases (15.4%), the individual was a pensioner. Student, plumber and waitress accounted for the remaining 3 cases (1 case each).

3.2.4.3. Etiology and source of CO. Death was unintentional in 69.2% (9 cases) of the positive CO poisonings. The remainders were suicides (4 cases, 30.8%). CO poisoning was the cause of death in the 4 suicides that presented positive levels of COHb in *postmortem* blood samples. The most common CO source were the fires (5 cases, corresponding to 38.5%); in 3 cases (23.1%), a defective gas appliance was found at the death scene; in 2 cases (15.4%), the sources of CO were burning charcoal briquettes in a confined space; a fireplace (1 case, 7.7%), a can containing burnt wood (1 case, 7.7%), and a fire pan (1 case, 7.7%) were also found. The source of CO was different in all 4 suicides: one identified has the result of a defective gas equipment; one can containing burnt wood; one fire pan; and the other case related to charcoal briquettes.

3.2.4.4. Autopsy findings. Cherry-red lividity was present in 8 (61.5%) positive fatal CO poisonings; in 4 (30.8%), lividity wasn't characterized because of skin pigmentation or thermal lesions; in one (7.7%) case, lividity was *bluish*. Nonetheless, all the 13 positive fatal CO poisonings presented cherry-red blood and viscera coloration.

3.2.4.5. Toxicological results. Mean % COHb in individuals with positive COHb analysis who died due to CO poisoning was 65 ± 18 (SD) %. COHb levels were significantly higher among positive suicidal CO poisonings than among unintentional cases (78 ± 17 vs. 58 ± 15 (SD) % COHb; Kruskal–Wallis Test for Independent Samples , $p = 0.013$). The lower COHb level found in a CO poisoning, with a positive analysis, was 42% and in 4 individuals (30.8%) COHb levels were lower than 50%. Medical history was unknown in these 4

Table 2
Yearly distribution of the CO poisonings with positive COHb analysis and corresponding characterization according to gender and etiology of death.

Year	Positive CO poisonings	Gender		Etiology	
		Male, *n* (%)	Female, *n* (%)	Violent, unintentional, *n* (%)	Suicide, *n* (%)
2000	5	4 (80)	1 (20)	5 (100)	0
2001	3	1 (33.3)	2 (66.7)	2 (66.7)	1 (33.3)
2003	1	1 (100)	0	0	1
2008	3	3 (100)	0	1 (33.3)	2 (66.7)
2010	1	0	1 (100)	1 (100)	0
Total	**13**	**9 (69.2)**	**4 (30.8)**	**9 (69.2)**	**4 (30.8)**

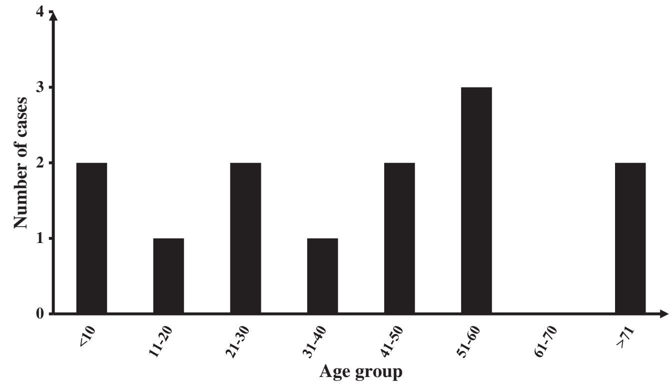

Fig. 4. Distribution of the fatal CO poisonings with positive COHb analysis, by age group.

cases and only one (25%) presented thermal lesions. None of these 4 individuals was alcohol intoxicated. Analysis for illicit drugs was negative in one of these cases (25%) and wasn't performed in 3 cases (75%). The same results were verified for prescription drugs analysis. Moreover, we found that all the 11 positive CO poisonings in which blood alcohol was tested (84.6% of all positive CO poisonings), were not alcohol intoxicated. Illicit drugs were analyzed in 5 cases (38.5%), all with negative results. In all 4 cases with a prescription drug analysis (30.8%), results were negative.

3.3. Negative analyses

COHb analysis was negative in 45 individuals (65.2% of all requests), including 26 males (57.8%) and 19 females (42.2%). The mean age was 60 ± 19 (SD) years. Death was of natural etiology in 10 cases (22.2%), unintentional in 31 cases (68.9%), suicide in 2 cases (4.4%), and homicide in 2 cases (4.4%). Politrauma was the most frequent cause of death among the negative cases (11 cases, 24.4%) (Fig. 5). Among natural causes of death, acute myocardial infarction was the most frequent, with 4 cases (8.8% of all negatives). In one case (2.2%) with a negative analysis request, CO poisoning was the cause of death. This former case, an accident involving a fire, presented cherry-red blood and viscera coloration, but *bluish* lividity and no thermal lesions.

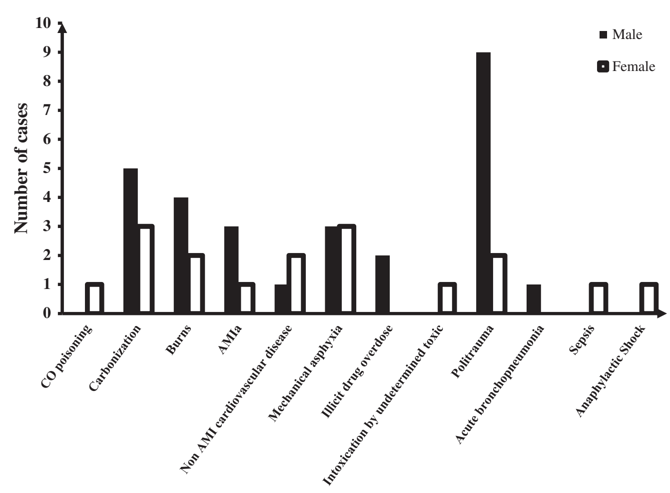

Fig. 5. Cause of death in males and females with a negative COHb analysis. [a]*AMI*, acute myocardial infarction.

4. Discussion and conclusion

In this study we did not only considered deaths caused by CO intoxication, but also those in which the suspicion of CO intoxication was not confirmed (cases with a positive analysis but a different cause of death, and cases with a negative analysis). Also unlike other studies,[6,7,15–17] we excluded no particular etiologies or sources of CO. Moreover, autopsy findings and their relevance in the differential diagnosis of CO intoxication as a cause of death, were analyzed. This subject is rarely addressed in surveys of fatal CO poisonings.[10] Trends in fatal CO poisoning over the last 11 years were reviewed through a broader perspective, when compared to the only existent studies carried out in our country.[18]

COHb analysis requests peaked in 2000 and 2005, the years with the higher number of forest fires in Portugal. The most frequently identified CO source was, indeed, the fires, but the higher request's number was achieved in March, and during winter, when forest fires are less frequent. Thus, our yearly, seasonal and monthly distribution of COHb analysis requests was, probably, more directly related to the prevalence of urban fires, rather than that of forest ones. Our results are in accordance with the generalized idea that CO intoxication is more frequent during winter months, because of the increased use of heating appliances, and diminished house ventilation,[19] confirmed according to our national reality by Sá et al. (2011).[20] This may also explain the seasonal distribution of CO deaths, more frequent during winter months and non-existent during summer.[6–8,16,21] CO poisonings were more prevalent in 2000, and never reached such huge numbers through the remaining years. Pinho Marques et al. (2002) reported 42 fatal CO poisonings between 1990 and 1999, the decade with the higher number of cases since the fifties.[18] It was expected to have a decrease on fatal CO intoxications between 2000 and 2010, due to an improved treatment,[20] the opening of new medico-legal facilities and the impact of these cases in national public media and prevention campaigns directed to the population.

Fatal CO poisonings are more prevalent among males,[7,15,22] an observation also supported by our own results (Table 2), since it is known that men engage in high-risk behaviors more often than women, such as manual work with fuel-burning tools, or appliances and their maintenance.[21] In our study, fire was the most common CO source and, according to Blanc and Kuschner (2007), more than one third of all firemen use protection masks less than half the time, during a fire suppression.[23] Moreover, in Portugal, firemen are still, mainly, male individuals. However, occupation was unknown in the majority of the CO intoxications, which makes it difficult to understand the role of occupation in gender differences.

The higher number of intoxications occurred between 51 and 60 year-olds (Fig. 4), against what was encountered by most of the authors, among the youngest and the eldest.[7,15] In fact, these studies involved only unintentional poisonings, and therefore, this difference may be explained by the particular age distribution of CO-related suicides.[6] Other age groups, namely those of children (<10), the young (21–30), middle aged (41–50) and the eldest (>70) are also a risk (Fig. 4). The younger people are less careful and preventive,[16] and the elderly are a risk group due to their limited mobility, poorer economic situation, likelihood of mistaking CO poisoning for fatigue or influenza-like illness, and comorbility.[21] Children have a higher metabolic rate and oxygen uptake.[4] CO poisonings were mainly unintentional (Table 2), which is in accordance to the literature.[6,8,16] In our study, a request was made in 6 suicides, representing 8.7% of all requests, an already expected percentage, since Sá et al. (2011) had concluded that, in seven hospitals of the north of the country, 10.8% of the CO-related intoxications were attempted suicides.[20] Intoxications of suicidal nature are more frequently fatal because COHb achieved levels are usually higher.[6] However, our suicides percentage is also higher than other reported fatal cases,[6,8,16] but we believe that this may be explained by the existent prevention measures to reduce the number of unintentional deaths, rather than due to an absolute increase in the CO-related suicides. In our study, the CO source was an heating appliance in all CO-related suicides. Unlike other studies,[6,22] we registered no suicides by inhalation of car exhaust fumes. Some of these refer to the late eighties and early nineties, when catalytic converters were still in development.[6] Most unintentional CO poisonings resulted from fires, as other authors also reported it.[7,22] This result emphasizes, first, the safety improvements in heating appliances and public awareness and, secondly, the necessity to further invest in fire prevention, namely through the mass generalization of smoke detector installation in Portuguese homes. In fact, a working smoke detector reduces, at least in 50%, the death risk, by fire, at home.[7]

Autopsy findings also are an important factor for a toxicological analysis request.[24] Accordingly, in over one half of the cases with a specific CO request, the victims presented thermal lesions (Table 1), and nearly one third presented characteristic cherry-red lividity. The same percentage of cases presented cherry-red blood and viscera coloration. On the other hand, these findings were present in some cases in which a source of CO was not identified. In our practice, the presence of a CO source at the death scene, and suggestive autopsy findings concur to a strong suspicion of CO poisoning. The absence of cherry-red lividity is not, however, a conclusive evidence that CO poisoning was not the cause of death. In fact, cherry-red livor was present in only 61.5% of the CO intoxications, a much lower percentage than that of Risser et al. (1995).[10] Also unlike the former authors, we found no association between COHb levels and the lividity type. A possible explanation could be that we also considered CO-intoxications caused by fire, and therefore, our cases included those in which lividity was not characterizable due to external thermal lesions but that could, otherwise, have presented cherry-red lividity. On the other hand, we found that cases with a positive analysis and thermal lesions were strongly associated with lower COHb levels, as also reported in other studies.[17,22,25] It is known that burns, instead of CO intoxication, can be the cause of death in, at least, 30% of fire victims.[25] We observed a mean % COHb of 65%, which is in conformity with the widely accepted threshold for fatal cases, 50 or 60%.[9] Older individuals presented lower COHb levels, observation also reported by Risser and Schneider (1995).[6] The elderly with underlying cardiovascular disease are less tolerant to CO pathogenicity[6,17] and this could explain our 4 cases in which CO poisoning was the cause of death, but COHb levels were lower than 50%. No medical history was available in all cases.

Blood alcohol, prescription and illicit drug analyses were negative in all the CO intoxication cases where these toxicological substances were also required. In fact, the above substances have been related to an increased risk of CO-related accidents, and to ingestion of large quantities of drugs before CO-related suicide attempt,[17,26] even though a study reported that the presence of drugs did not change the cause of death.[26]

It is not surprising that politrauma was the most common cause of death among our negative cases (Fig. 5), because circumstantial information is a decisive motivation to request a toxicological analysis, and many of the fire victims in our study were involved in car accidents and explosions, situations that resulted in fatal craneoencephalic or toracoabdominal lesions but in which CO could have played an important role as the cause of death. The same applies to deaths due to thermal lesions, also an important differential diagnosis among unintentional deaths. Differential diagnosis with natural death, and particularly cardiovascular disease, is also a reality in our forensic practice (Fig. 5). The elderly, more prone to severe cardiovascular disease, are also a risk group for CO

intoxication and cases in which, due to unspecific circumstantial information, absence of cherry-red livor and presence of arteriosclerosis and coronary arteries calcification, differential diagnosis was not straightforward, have been reported.[12] The fact that delayed death by CO intoxication is consistent with negligible COHb levels, may impose further diagnostic challenges.[27]

In summary, we have demonstrated that, in our practice, forensic aspects of CO poisoning interact in a complex way. Establishing CO poisoning as a cause of death requires a strong suspicion, based on suggestive circumstantial information and autopsy findings, and levels of COHb higher than 50%. Even when these factors are reunited, differential diagnosis is not straightforward. This study also emphasizes the role played by public prevention campaigns, and improvement of heating appliances in reducing the number of unintentional CO poisonings, and the importance of encouraging further prevention measures regarding urban and forest fires, still the major source of CO among us.

Ethical approval

None.

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None.

Conflict of interest

We declare that there is no conflict of interest.

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